Delaware County Electric Cooperative

DR Capability and Predictability

INITIAL FINDINGS | NOVEMBER 15 2013

NRECA
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NRECA-DOE SMART GRID DEMONSTRATION PROJECT | DE-OE0000222

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DR Capability and Predictability

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Prepared by

Craig Miller and T.J. Kirk
Cooperative Research Network
National Rural Electric Cooperative Association
4301 Wilson Boulevard
Arlington, Virginia 22203-1860

for

U.S. DOE/NETL
Morgantown Campus
3610 Collins Ferry Road
PO Box 880
Morgantown WV 26507-0880

PROJECT MANAGER: CRAIG MILLER, PHD

PRINCIPAL INVESTIGATOR: TOM LOVAS

The National Rural Electric Cooperative Association

NRECA is the national service organization for more than 900 not-for-profit rural electric cooperatives and public power districts providing retail electric service to more than 42 million consumers in 47 states and whose retail sales account for approximately 12 percent of total electricity sales in the United States.

NRECA's members include consumer-owned local distribution systems — the vast majority — and 66 generation and transmission (G&T) cooperatives that supply wholesale power to their distribution cooperative owner-members. Distribution and G&T cooperatives share an obligation to serve their members by providing safe, reliable and affordable electric service.

About CRN

NRECA's Cooperative Research Network™ (CRN) manages an extensive network of organizations and partners in order to conduct collaborative research for electric cooperatives. CRN is a catalyst for innovative and practical technology solutions for emerging industry issues by leading and facilitating collaborative research with co-ops, industry, universities, labs, and federal agencies.

CRN fosters and communicates technical advances and business improvements to help electric cooperatives control costs, increase productivity, and enhance service to their consumer-members. CRN products, services and technology surveillance address strategic issues in the areas:

- Cyber Security
- Consumer Energy Solutions
- Generation & Environment
- Grid Analytics
- Next Generation Networks
- Renewables
- Resiliency
- Smart Grid

CRN research is directed by member advisors drawn from the more than 900 private, not-for-profit, consumer-owned cooperatives who are members of NRECA.

Contact Information

National Rural Electric Cooperative Association
Cooperative Research Network ™
4301 Wilson Boulevard
Arlington, VA 22203-1860
703.907.5500

Table of Contents

List of Figures

List of Tables

FOREWORD

The National Rural Electric Cooperative Association (NRECA) has organized the NRECA-U.S. Department of Energy (DOE) Smart Grid Demonstration Project (DE-OE0000222) to install and study a broad range of advanced Smart Grid technologies in a demonstration that involves 23 electric cooperatives in 11 states. For purposes of evaluation, the technologies deployed have been classified into three major sub-classes, each consisting of four technology types, the status of which have been reported in the Interim Technology Report of April 2013:

Enabling Technologies:	Advanced Metering Infrastructure Meter Data Management Systems Telecommunications Supervisory Control and Data Acquisition
Demand Response:	In-Home Displays & Web Portals Demand Response Over AMI Prepaid Metering Interactive Thermal Storage
Distribution Automation:	Renewables Integration Smart Feeder Switching Advanced Volt/VAR Control Conservation Voltage Reduction

To demonstrate the value of implementing the Smart Grid, NRECA has prepared a series of single-topic studies to evaluate the merits of project activities. The study designs have been developed jointly by NRECA and DOE. This document is the initial report on one of those topics, based upon the progress of the activity to date. The project team will be monitoring the progress of the various cooperative activities during the remaining term of the demonstration to close identified information gaps and identify additional information that will be of benefit to the merit evaluation. This document and the other single-topic studies then will be updated, as appropriate, for consideration in the final Technology Performance Report at the close of the Smart Grid Demonstration Project.

Delaware County Electric Cooperative—DR Capability and Predictability

1. INTRODUCTION

Delaware County Electric Cooperative (DCEC) is instituting a Demand Response (DR) program so as to be able to shed demand when requested by the New York Independent System Operator (NYISO). This activity has been supported by the National Rural Electric Cooperative Association (NRECA) U.S. Department of Energy (DOE) Smart Grid Demonstration Project through the implementation of advanced metering infrastructure (AMI) and load control switches. Demand response programs for bidding into an ISO market typically have relied on larger industrial-scale customers. However, with the advent of widespread AMI adoption and load control switches for residential devices, it is possible for distributed residential loads to bid into the market as a cohesive system. DCEC selected water heaters as the best option for its DR program because they have several advantages. They draw a significant amount of load, can store energy thermally, and are commonplace—at least one in every modern house.

2. RESEARCH OBJECTIVES

a. Demonstrate how much load—and how quickly—DCEC can reliably shed through a DR program with water heaters.
b. Determine the best way to apply this technology to decrease costs without compromising member satisfaction.

3. BACKGROUND: THE NRECA/CRN SMART GRID DEMONSTRATION PROJECT

a. *NRECA Overview*
NRECA received a $34 million Smart Grid Demonstration research grant from DOE. The resultant project, coordinated by NRECA's Cooperative Research Network (CRN), purchased the necessary equipment on behalf of NRECA's participating member cooperatives. Ancillary services related to the equipment are contracted directly between the supplier and NRECA's member cooperatives. Electric distribution cooperatives have been evaluating the potential benefits of new technologies that could help increase operational efficiencies and improve service. Twenty-three of NRECA's member electric cooperatives have deployed more than 250,000 smart grid components across the country to test the value of the new technologies for cooperative consumer-members.

b. *DCEC Overview*
DCEC of Delhi, New York, is a non-profit rural electric cooperative serving more than 5,100 members in 21 towns across four counties—Delaware, Schoharie, Otsego, and Chenango. Formed in 1941 as a corporation and converted in 1942 to a cooperative, DCEC has been a staple of its community for more than 70 years. Its employees now manage more than 800 miles of line, compared to just 8.2 miles in 1944. Its primary mission is to provide a safe, reliable, and cost-effective electric power supply to its members.

4. EXECUTIVE SUMMARY OF RESULTS

a. *Principal Findings*

The demand curve for both the control and test data followed a similar trend of declining and then rebounding for the period of time sampled. However, during the period the demand response program was active, the demand reduced at 2.5 kW/minute, compared to 1.2 kW/minute without the DR program. On average, the inflection point of the test data was 55 kW lower and 80 minutes earlier than the control data. However, following the trough, the test loads rebounded faster and, at the end of the period measured, were 112 kW higher than the control loads.

Each additional water heater in the study lowered demand by an average of 0.6 kW during the test. This is in line with the findings of other studies of Demand Response.

b. *Recommendations*

Based on the results of the test and the baseline provided by the control data, this DR program seems best suited for peak-shifting or bidding into the ISO market as a short-term DR program. The rebound effect that follows the DR program makes it unlikely that total load will be reduced.

c. *Further Research*

Further research is needed to test the reliability of this program in different situations. This research should center on running the program at different times of the day and during different seasons. This is needed for two reasons. First, this program relies on the use of water heaters, which are subject to daily patterns of use; most hot water is used in the evening or mornings. Second, temperature affects hot water use, although this variable will be primarily seasonal.

5. LITERATURE/TECHNOLOGY REVIEW

a. *Previous Approaches to Residential Direct Load Control*

Using water heaters to shed load at a specific time is an example of Demand-Side Management (DSM), which encompasses a host of techniques and technologies to optimize energy use on the consumer side. DSM includes Energy Efficiency (EE) measures, Time-of-Use pricing, Demand Response, and Spinning Reserve.[1] All of these measures are intended to reduce load over time, especially through reducing energy use at its high points or peaks. Energy must be produced in a quantity great enough to satisfy the single highest point of demand safely but, in meeting this requirement, significant amounts of energy are wasted. By bringing the peak lower and the "troughs" higher, less energy production is needed to meet high peaks.[2]. In addition to being more efficient, the ability to reduce load reliably when necessary can help lower the incidence of rolling blackouts. In California, a rolling blackout in June 2000 occurred because a 50,000-MW system was short 300 MW, an amount that represented 0.006% of the total load.[3] Had an effective DSM program been in place to reduce

[1] (Palensky and Dietrich, 2011, p. 381)
[2] (Saffre and Gedge, 2010, p. 300)
[3] (Saele, 2011, p. 102)

demand by the necessary amount, the blackout could have been avoided. Events like this cost utilities more than just money—consumer satisfaction and trust also are lost when the grid does not perform reliably.

b. *DLC Approach to DR*

The application of DSM studied in this paper is most accurately classified as a DR program using a Direct Load Control (DLC) approach, in which the utility operator has control over the customers' water heaters and can determine the most optimal time to shed their load. In contrast, other DR programs require direct member participation and often offer incentives to encourage energy-saving behavior at specific times. For example, to get consumers to adjust their thermostats at peak demand times, a utility may offer a rebate on their electricity bills, but the utility cannot mandate conservation or remotely turn off an appliance under these conditions. DSM, whether consumer or utility controlled, is different from energy efficiency measures, which lower demand by a specific amount across the load levels. As opposed to energy efficiency measures, DSM (and DLC in particular in this study) does not lower energy consumption, just the demand at a given time. This leads to a rebound, or payback effect, of increased demand following the period of load shed. **Figure 1** illustrates this impact on demand over time as well as the difference between DSM and EE measures:

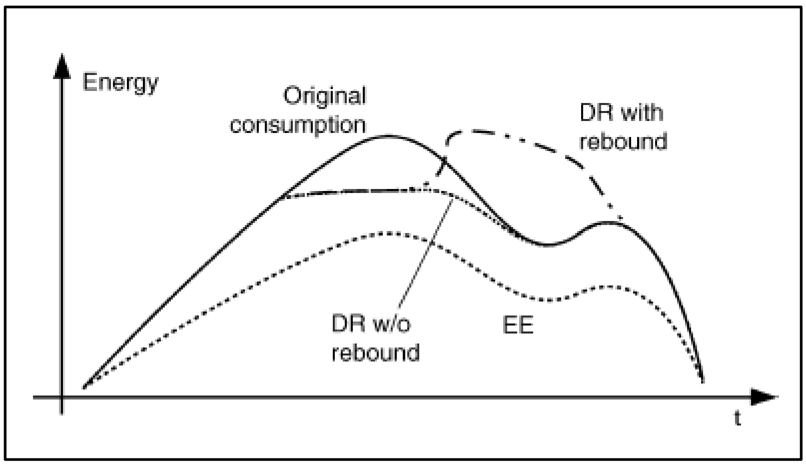

Figure 1.[4] Impact on Demand over Time and Difference between DSM and EE Measures

c. *Previous DLC Water Heater Studies*

A study in Norway estimated the payback effect for the hour following the DR program to be 0.2 kW per household or water heater (typically, there is only one water heater per household).[5] This means that utility operators need to be careful when instituting a DR program to avoid creating a new peak in demand as they shift load.

The other primary issue is shedding load for such a period of time that it inconveniences consumers; only certain appliances lend themselves to this task. For example, a refrigerator DR program to directly control the temperature of the appliance might leave consumers' food too warm if the system is left to idle for too long. Many

[4] (Palensky and Dietrich, 2011, p. 382)
[5] (Torgeir, 2009, p. 1)

appliances do not make good targets for DLC, despite being used widely and having a substantial power factor, because they have no way to store energy (e.g., TVs) or the consumer is concerned that the program might negatively impact them (e.g., A/C units). However, water heaters make a good target for DR programs because they consume a significant amount of energy (up to 30% of household loads in some areas); the heating element of a water heater typically is a resistor, making it simple and flexible to turn on and off; and water's high heat capacity allows it to act as a thermal energy storage device, meaning that it can be turned off for longer periods of time without any consumer dissatisfaction.[6] An ideally operated DR program would average out energy consumption in such a way that consumers' actions would be unaffected but still provide ample peak reduction or shifting for the utility.

Another area of interest for DR is the amount of load that can be shifted. This is essentially a function of how many consumers are participating and the power rating of the water heater. Previous testing done in Norway found average demand reductions from 0.5 kW to 1 kW for each standard electrical water heater and 2.5 kW for hot water space heating systems.[7][8] American water heaters tend to have a slightly higher power rating than their European counterparts, by about 1 kW, meaning that the per capita reduction would be even higher. However, proposed efficiency measures in the U.S. may threaten the viability of using residential water heaters for DR if they are passed. Another factor is the increasing ubiquity of smart meters and appliances, which will make deploying DR programs easier and more cost-effective.

6. METHODOLOGY

Under the Smart Grid Demonstration Project, DCEC performed DR tests using residential water heaters. A total of 10 tests were run throughout summer 2013, starting on June 25 and ending on August 8. The study group included 573 water heaters of varying sizes (30 gallon, 50 gallon, 80 gallon, and a farm class), but with similar heating element power ratings (3–3.8 kW for the non-farm classes and up to 4.5 kW for the farm classes). Each class of water heaters was divided into seven subgroups (except for the farm class, which is divided into two) for organizational purposes during the DR program. These subgroups then were recombined to form 16 "blocks" of roughly equal size that were used throughout the test to ramp the water heaters on and off the program.

The start- and stop-time temperatures were recorded for each test at two locations. System load data were collected every 5 minutes for 6.5 hours during each test day and included the demand of each of the four feeders, the aggregate demand, the percentage of each type of water heater in "shed mode," and the step of the test (each step corresponded to the number of blocks of water heaters in shed mode according to a defined matrix). The DR program itself functioned by shedding water heaters on and off (shedding a water heater means turning off its load control switch so that it cannot be turned on). However, the data collected do not show whether or not a water heater entering shed mode was off or on, or whether it would have turned on during shed mode or not. This means that shedding a water heater does not guarantee a reduction in demand,

[6] (Diao, 2012 p. 1)
[7] (Torgeir, 2009, p. 20)
[8] (Saele, 2011, p. 107)

but only that it cannot be turned on. The key takeaway here is that the program would be more effective in an area where water heaters are constantly in use, making them a larger proportion of the load.

Data collection began an hour before an initial command was sent out to water heaters to begin entering shed mode. In most tests, data collection began at 11:00 and the initial command was at 12:00 (a few tests started as late as 11:15, pushing all events back by a corresponding amount). The initial command was always to go to step 8 (out of the 16 total steps), which shed eight blocks of water heaters—roughly 50% of the water heaters. After beginning, another block was shed every 5 minutes, as the steps increased, until step 16, when 100% of the water heaters were shed. All water heaters remained in shed mode for 1 hour—marginally longer in some tests. After the full shed, the water heaters gradually were "unshed," or allowed to turn back on. The return to service of the water heater loads was staggered by using the step matrix and set-time delays in the defined blocks to minimize the establishment of a subsequent peak loading condition. Similar to the stepping up process, the system stepped down once every 5 minutes. The goal was to avoid a condition in which all of the water heating equipment returned to service at the same time, which could have amounted to a coincident loading peak.

The stepping down process took 80 minutes, until there were no water heaters left in shed mode. Data were collected for another 2.5 hours after all of the water heaters were unshed to assess the amount of "load payback" or increase in demand due to the DSM program. Data collection ended for most tests at 17:30, although tests that started later also ran later.

Along with the test data, 7 days of load-level data were provided from the same weekdays during the same time frame. These data, collected from the same feeders and at the same intervals (every 5 minutes), were the control data for the experiment. This allowed for a baseline comparison of how the demand curve would have looked without the DR program.

In addition to the process outlined above, there are several important points about the study.

First, the blocks used to control which water heaters were shed were created because DCEC uses a Power Line Carrier (PLC) communications system that cannot accommodate requests to all of the blocks if they were to be initiated simultaneously. This limits how quickly demand can be reduced through this program because not all the water heaters can be shed at once. Second, the shedding schedule operated in a "round robin" mode, also known as "first-in, first-out." In this system, the first block of water heaters shed at step 1 will be the first block unshed at a later time. For example, at Step 14, the command sequence would "shed" 86% of the 30/40-gallon units, 86% of the 50- gallon units, 100% of the 80-gallon units, and 100% of the farm units. If the system stays at step 14, unshed 30-, 40-, and 50-gallon units would be commanded to be shed to maintain the 86% value, while those that have been in shed mode the longest will time out and be allowed to return to normal operation. The 80-gallon and farm units will remain in shed mode, as allowed by the set-time delays. The command sequence has knowledge of the subgroups in shed and will move to the unshed subgroup as needed according to the system strategy matrix, following set-time delays. This is all done to avoid inconveniencing one group of members with longer shed times.

Finally, an error source exists in each of our samples, originating with the sampling process in DCEC's data acquisition system. DCEC's feeder measurements do not register changes in demand smaller than 48 kW, 24 kW, 21 kW, or 19.2 kW, depending on which feeder it measures. While this quantization noise is relatively small, it could cause sampling error because the signal from this program is also small; each block should reduce demand by only 20 kW when shed, while the error is 17.5 kW RMSE. The error is largely ignored for this analysis because it is normally distributed around zero and, with a sufficient sample of tests, averages out to a negligible factor.

7. ANALYSIS

The primary goal was to find out how much load could be reduced, and in what time frame. Thus, the first analysis was conducted to show how demand changes as water heaters are shed. **Table 1** shows the slope of the relationship between demand and percentage of water heaters in shed mode.

Table 1. Slope of Relationship between Demand and Percentage of Water Heaters in Shed Mode

Date	Test No.	Weekday	Total kW Reduction at 100% Shed	Hours to Inflection Point
6/25/2013	1	Tuesday	21.84	1.82
7/5/2013	2	Friday	498.53	41.54416667
7/15/2013	3	Monday	345.45	28.7875
7/16/2013	4	Tuesday	307.96	25.66333333
7/17/2013	5	Wednesday	401.92	33.49333333
7/18/2013	6	Thursday	266.11	22.17583333
7/30/2013	7	Tuesday	324.36	27.03
7/31/2013	8	Wednesday	420.84	35.07
8/2/2013	9	Friday	384.1	32.00833333
8/8/2013	10	Thursday	640.71	53.3925
Test Averages:			**356.814**	**29.7345**

This shows that, for each additional 1% of water heaters shed, demand dropped by 3.56 kW. Given that there were 573 water heaters in the study, this averages out to 0.6 kW per water heater—a number similar to the reduction found in previous studies. This shows that for almost every test, demand drops during the implementation of the DR program, but we need to know the time frame of this effect as well.

Figure 2 provides an overview of all of the demand curves.

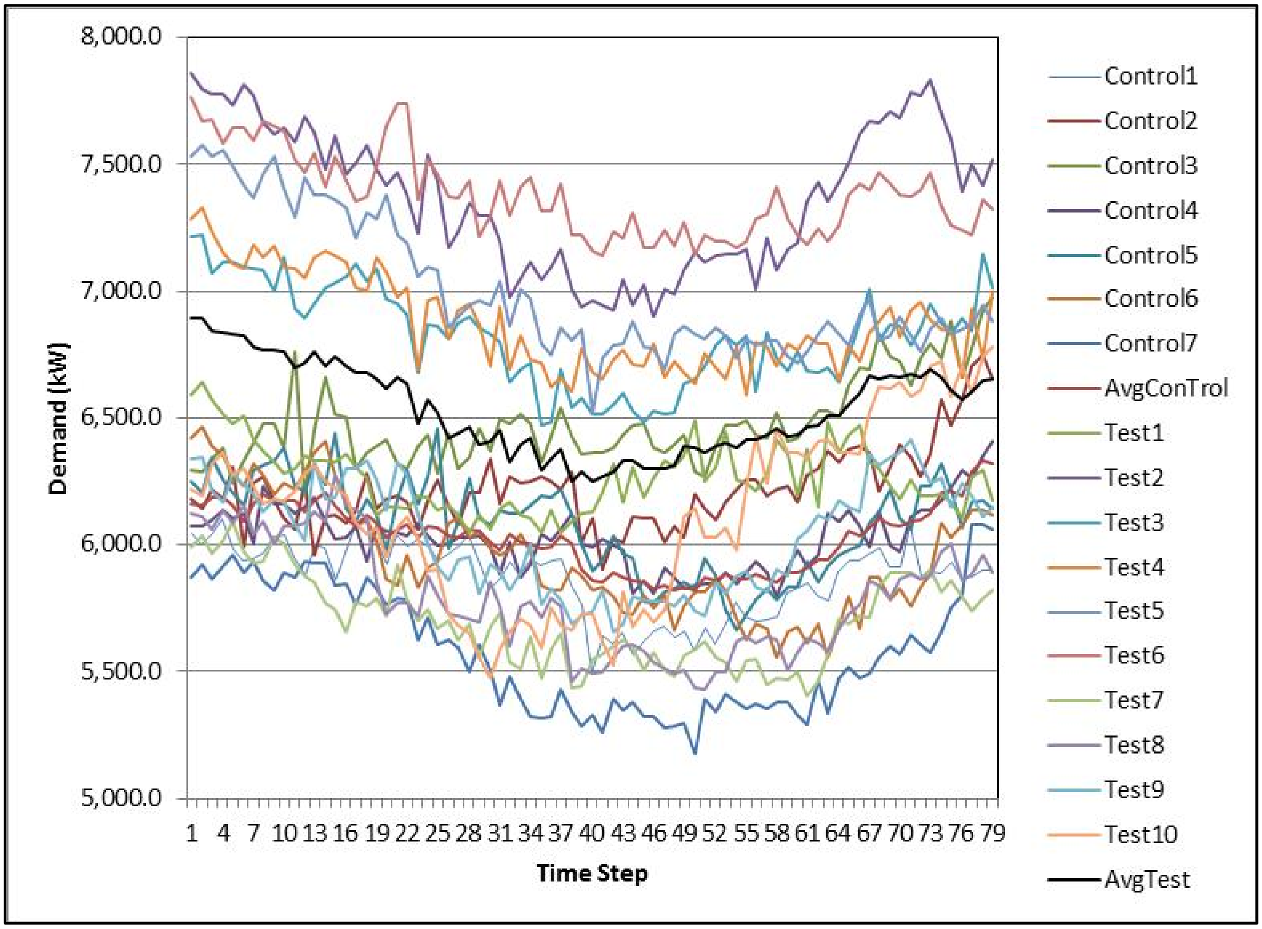

Figure 2. Overview of All Demand Curves

From these data, it is difficult to see trends or patterns amidst the noise. However, the averages of the test and control data over the period the test was conducted and normalized by their starting value, shown in **Figure 3**, display a U-shaped pattern for both sets of data. While both lines have a similar trend, the test data drop further and more sharply than the control data.

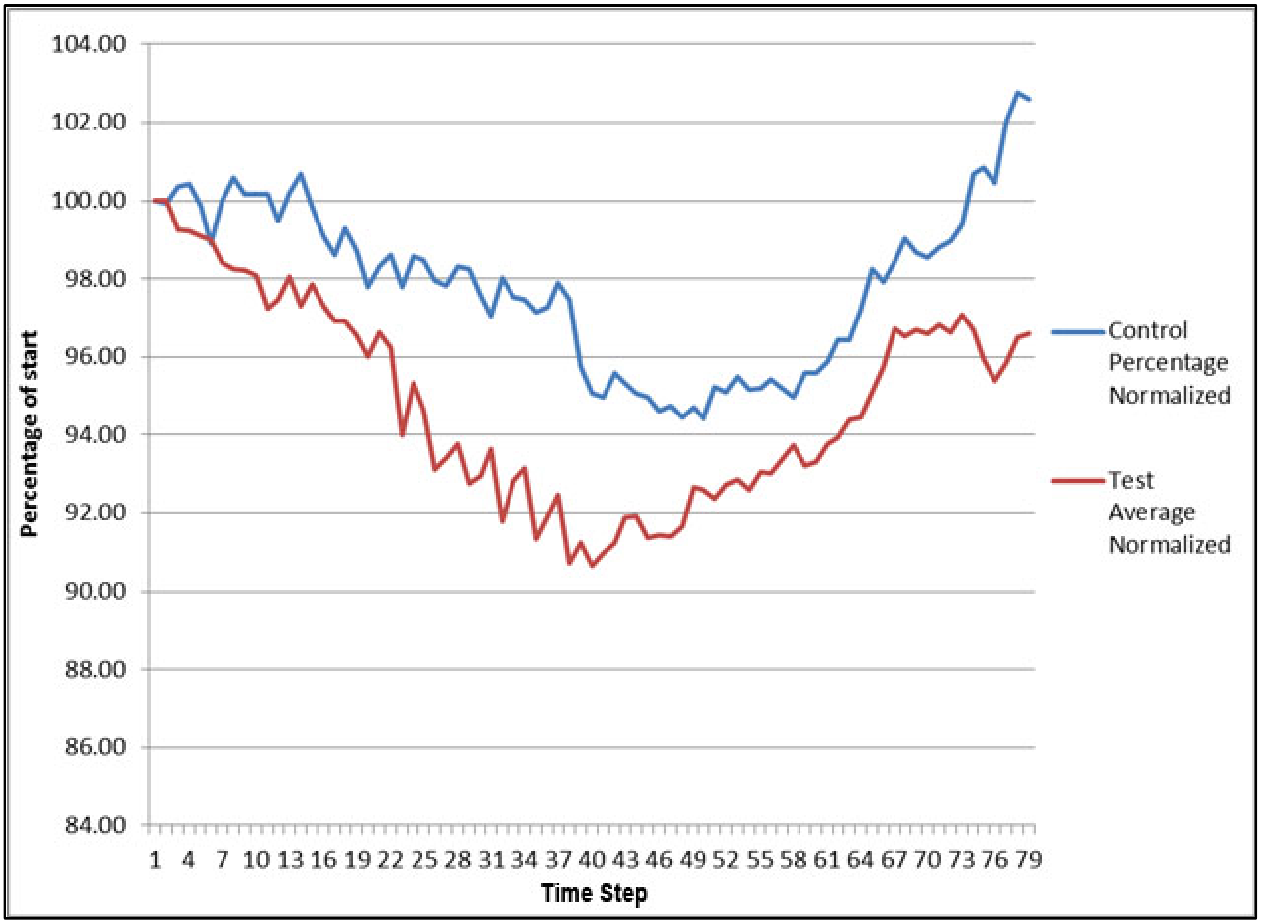

Figure 3. Averages of Test and Control Data over Test Period

The next challenge was to figure out the inflection point of the DR program—when does demand start trending upward again? In an ideal world, this point would be at the end of step 16, right before water heaters start cycling out of shed mode. However, for various reasons, including system lag and other demand factors, the bottom of the curve does not exactly match the end of the DR full shed mode. To find the inflection point between where the demand is decreasing and increasing, the moving R-squared product was calculated. This means that every data point inside the middle 50% was assumed to be the potential inflection point; the linear regressions on either side then were calculated, and the R-squared values of each side were multiplied together. The point associated with the greatest of these products was selected as the true inflection point. This method ensured that each side had the greatest optimal linear fit, but not at the expense of making the other side a poor fit. The moving-R method then was applied to the control data to see how the breakpoints and rates of change compared to baseline data. See Appendix A for more information on the moving R-squared technique.

In **Figure 4**, the graphs of each test result show how demand changed over time during the test. The left vertical axis is demand in kW, the right vertical axis is the R-squared product of that point (corresponding to the gray line), and the horizontal axis is the time stamp in 5-minute intervals (for example, "40" corresponds to 3 hours and 20 minutes after the start of data collection, or 14:20 in most tests). The first vertical red line marks the start of the load shedding, the second red line is the start of the "full-shed" (all water heaters are in shed mode), and the third red line marks the end of the full-shed as the water heaters begin coming back online. The red squares are demand readings during the downward reduction, and blue squares are demand readings as demand begins to rise again. The point between the red and blue squares is the inflection point, based on the product of their R-squared values.

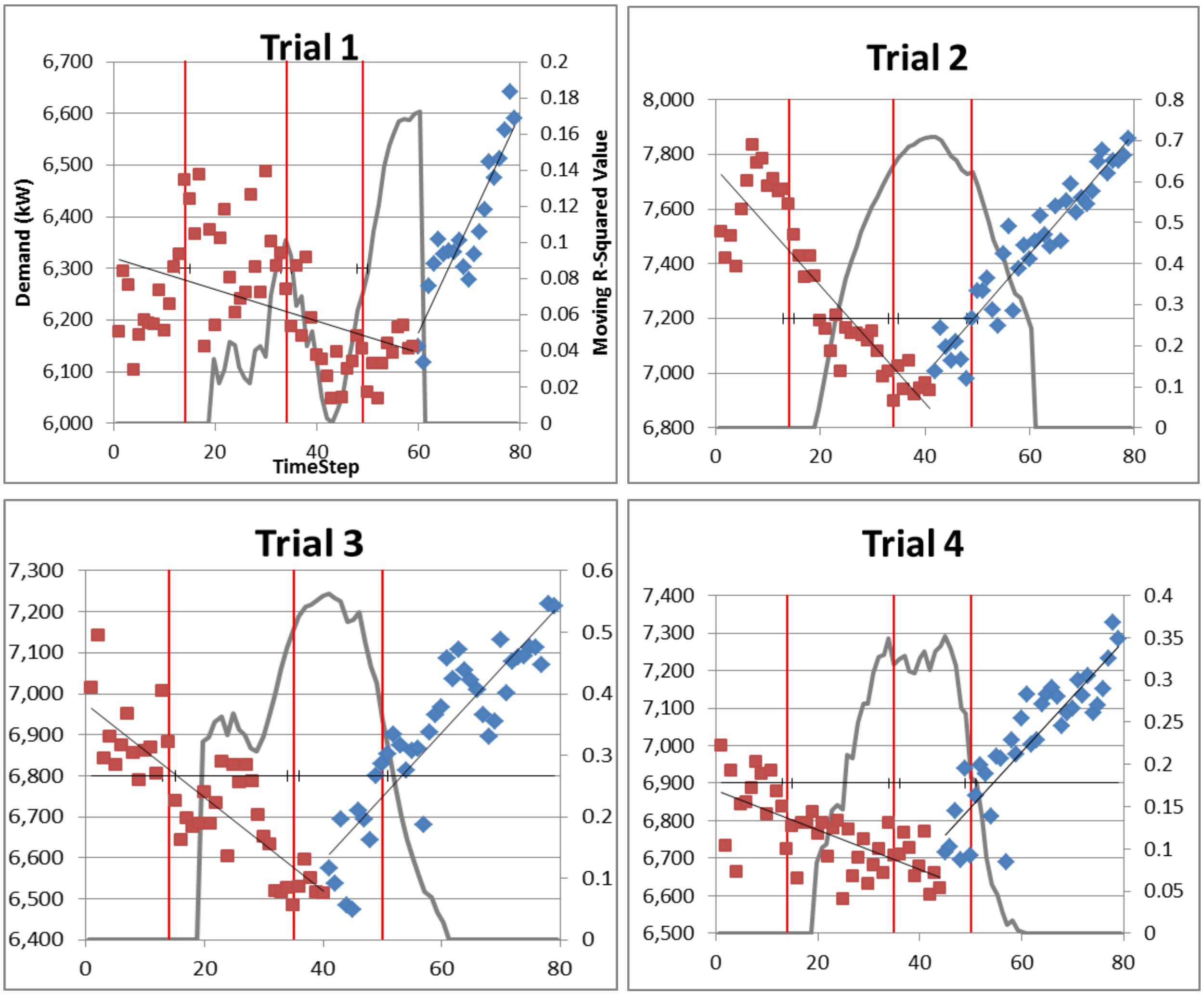

Figure 4. Demand Changes over Time during Each Test

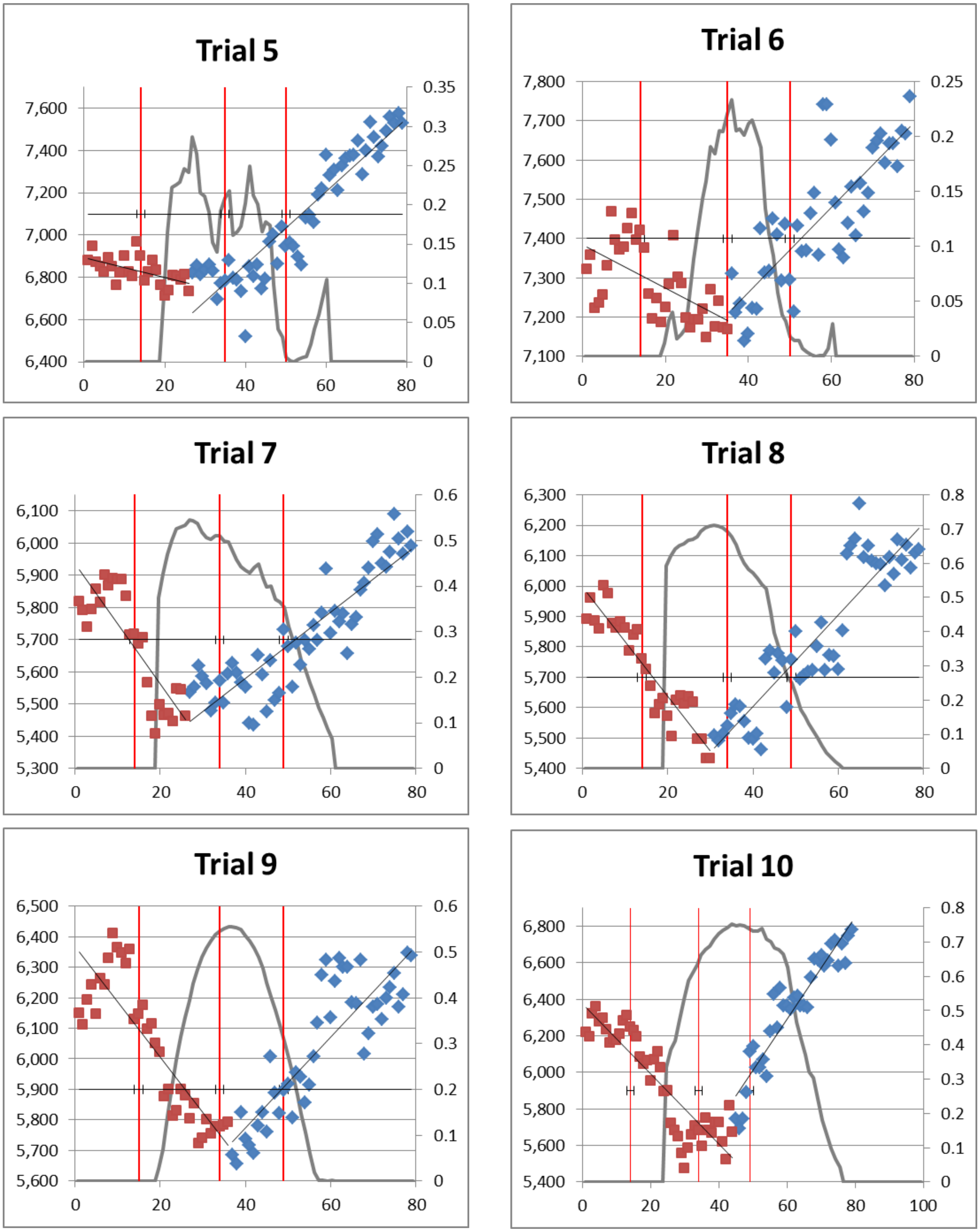

Figure 4. Demand Changes over Time during Each Test (continued)

The important characteristics of the data displayed above are how quickly demand falls and rises, and the location of the inflection point (or breakpoint). **Table 2** lists these numbers for all the test and control data.

Table 2. Rise and Fall of Demand, and Inflection Points

Date	Test No.	Weekday	Inflection Point	Total kW Demand Reduction	Total kW Demand Increase
Test Data					
6/25/2013	1	Tuesday	60	139.9504	400.786
7/5/2013	2	Friday	42	599.06	815.961
7/15/2013	3	Monday	41	308.475	591.964
7/16/2013	4	Tuesday	45	162.9608	503.948
7/17/2013	5	Wednesday	27	62.2635	898.976
7/18/2013	6	Thursday	36	121.3696	465.088
7/30/2013	7	Tuesday	27	243.243	534.456
7/31/2013	8	Wednesday	31	304.198	721.92
8/2/2013	9	Friday	37	398.222	625.002
8/8/2013	10	Thursday	45	595.262	950.47
Test Averages			**39.1**	**293.50043**	**650.8571**
Control Data					
6/26/2013	1	Wednesday	48	-281.3908	331.421
6/27/2013	2	Thursday	38	55.2168	562.561
7/2/2013	3	Tuesday	70	148.68	236.817
7/11/2013	4	Thursday	54	-213.896	466.975
7/12/2013	5	Friday	54	-367.116	538.575
7/29/2013	6	Monday	60	-581.21	546.706
8/5/2013	7	Monday	56	-613.284	679.926
Control Averages			**527.0603878**	**54.28571429**	**-259.456114**

This information confirms that there is a distinct difference in the rates of change. The DR program reduces demand at almost twice the rate of the control group (2.5 kW/minute and 1.28, kW/minute, respectively) and reaches the local minimum in a much shorter time frame (80 minutes, on average). As shown in **Figure 5**, visualizing these data using the averages of the data clearly shows the impact of the load-shedding program:

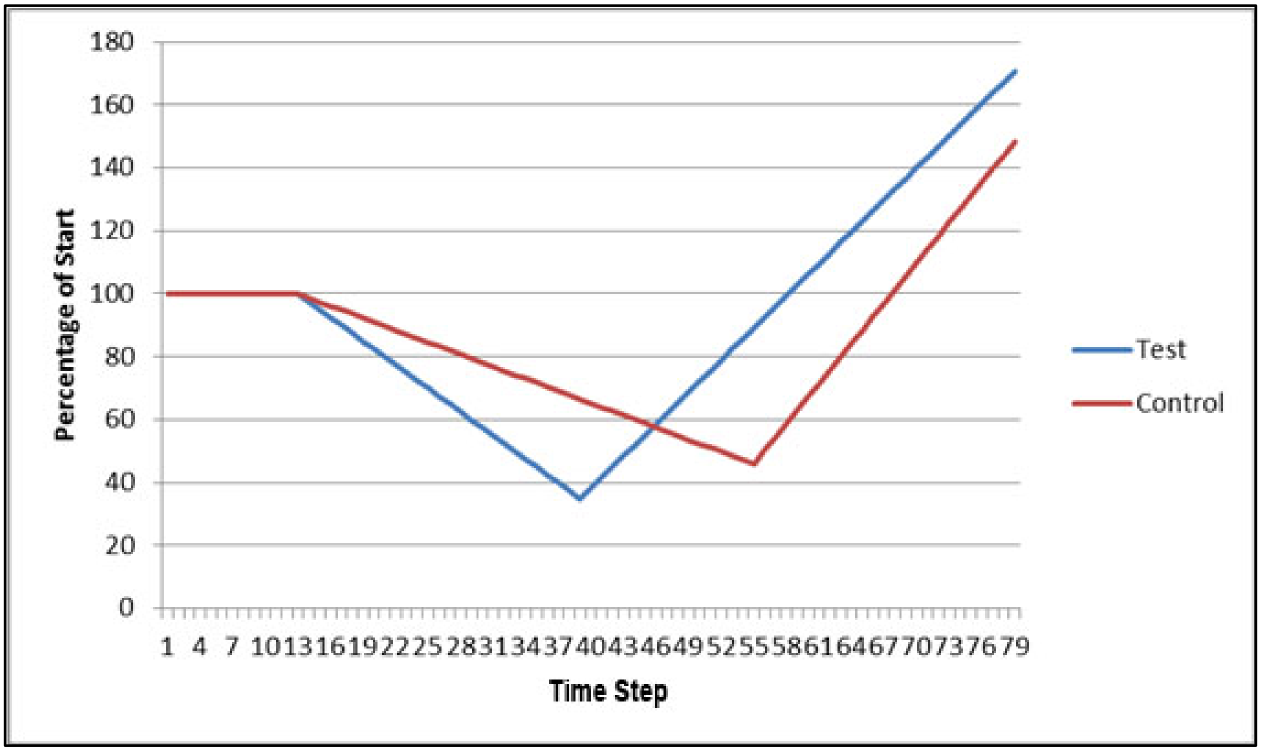

Figure 5. Rates of Change for DR Program and Control Group, Data Averages

8. DISCUSSION OF RESULTS OF THE DEMONSTRATION

This study did not find any surprises in the amount of demand reduction by shedding water heaters. Similar to the studies conducted in Norway, demand dropped roughly one-half a kilowatt for each water heater shed. The study also showed the impact of the payback effect. Close consideration needs to be given to this phenomenon in deciding when to use this program so as to avoid accidentally creating a new peak.

As the data show, the DCEC DR program is capable of reducing load in a timely and predictable fashion. In total, using the load-shedding technology at full shed reduced load by 356 kW from the start, on average. However, this number needs to be put in the context of the control data. The average local inflection point of the test data was 55 kW lower and 80 minutes earlier than the control data's average inflection point. Potential uses for this program include peak-shifting and possible bidding into the NYISO market. For peak-shifting, the cooperative would be concerned with its own load curve and associated peaks. This could help the co-op smooth and lower demand, thus resulting in lower demand charges from the New York Power Authority (NYPA) and an improved load factor. An improved load factor helps to limit expensive incremental energy purchases during the winter months, at the time when DCEC exceeds its contractual limit for the purchase of low-cost hydro power provided by NYPA. Both of these methods result in financial savings for the cooperative and its consumer-members. Failure of the DR system results in higher demand charges to DCEC and increased purchases of expensive incremental energy for the cooperative in the NYISO market.

A markedly different strategy would be to bid into the NYISO market, either for uniform, contracted reductions or non-uniform sporadic reductions. This study and analysis will assist the co-op in judging whether to approach the NYISO to request the ability to participate or bid as a DR resource through the aggregation of controlled electric domestic water heating, which to our knowledge has not been done historically. Depending upon the findings of this study, DR programs similar to DCEC's controlled electric water heating program could be implemented by other distribution cooperatives or municipal electric systems in New York State. Uniform contracted reductions would require DCEC to hard-shed demand for the contracted kW level when requested by the NYISO. This would be a more consistent and valuable contract. If the co-op is unable to meet the contracted level with its DSM program, other loads would have to be shed. Non-uniform sporadic reductions are issued by NYISO for various levels at different times. DCEC would have the choice of accepting the terms of the reduction and then shedding load to reach that level. For these applications, the co-op would be paid for its reductions as a resource. If DCEC signs up for either of these contractual agreements and is unable to meet the level required, there could be monetary penalties or forfeiture of payments. However, the cooperative is first and foremost concerned with not compromising consumer satisfaction. While the tests clearly demonstrate the feasibility of its DR program, this has not yet been tested in all temporal or climatic conditions. Further research is advisable before signing a hard contract. It is important for DCEC to fully characterize the ability of its DR load control program to meet the "step function" expectation assumed by the NYISO for any DR participant; if it is unable to do so, then it must judge its value as some sort of "modified" participant.

9. CONCLUSIONS

The DCEC DR program successfully reduced demand in a reliable and predictable manner, but it is of limited capability regarding how much demand it can reduce, given the small differential between the inflection point in demand of the test and control data. Further research is needed to strengthen the reliability aspect of these results by testing the program at different times of the day, weekends, and seasonally. In addition, collecting more control data to create a "typical load curve" for each season would aid in the analysis. If more water heaters were given load control switches and added to the study, the capability of the program should increase as well. As long as large-capacity resistance water heaters continue to be used by consumer-members, cooperatives can make use of DR programs for a variety of purposes. The idea of cooperatives bidding into ISO markets using dispersed residential load controls is an innovative use of Smart Grid technology that is likely to proliferate in the future.

10. RECOMMENDATIONS FOR FURTHER STUDY

Further avenues for future research and project development are numerous. The test should be conducted again at different times of the day, on weekends, and in different types of weather throughout the year. As these tests are conducted, regular control data for the same times should be collected the day following or preceding the test. By running tests throughout the year and comparing the results, DCEC will have a better understanding of its program at different times and be able to leverage it more effectively. Additionally, the program should be expanded to include more residences, if possible. A similar study could be undertaken in different locations and using different appliances. For example, tying air conditioning into the program in this location is likely not to be practical, as there is little market penetration of residential air conditioning load in the DCEC service area, but such a step could be viable in the warmer southwestern U.S. Future study will help strengthen our understanding of the predictability and capability of these DR programs.

11. REFERENCES

Albadi, M. H. 2007. "Demand Response in Electricity Markets: An Overview." Power Engineering Society General Meeting, 1–5. doi: 10.1109/PES.2007.385728.

DeAndrea, P., personal communication, July 25, 2013−November 8, 2013.

Diao, R. 2012. Electric Water Heater Modeling and Control Strategies for Demand Response. Power and Energy Society General Meeting, 1-8. doi: 10.1109/PESGM.2012.6345632.

Grayson, H. C. 2006. "Innovative Approaches to Verifying Demand Response of Water Heater Load Control." IEEE Transactions on Power Delivery 21(1), 388–397. doi: 10.1109/TPWRD.2005.852374 http://ideas.repec.org/p/ssb/dispap/479.html.

Kondoh, J. 2011. "An Evaluation of the Water Heater Load Potential for Providing Regulation Service." IEEE Transactions on Power Systems 26(3), 1309–1316, doi: 10.1109/TPWRS.2010.2090909.

Palensky, P. P., and D. D. Dietrich. 2011. "Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads." IEEE Transactions on Industrial Informatics 7(3), 381–388, doi: 10.1109/TII.2011.2158841.

Ruisheng, D. 2012. "Electric Water Heater Modeling and Control Strategies for Demand Response." Power and Energy Society General Meeting, 1–8, doi: 10.1109/PESGM.2012.6345632.

Saele, H. 2011. "Demand Response from Household Customers: Experiences from a Pilot Study in Norway." IEEE Transactions on Smart Grid 2(1), doi: 10.1109/TSG.2010.2104165.

Saffre, F. S., and R. G. Gedge. 2010. "Demand-Side Management for the Smart Grid." Network Operations and Management Symposium Workshops, 300–303, doi: 10.1109/NOMSW.2010.5486558.

Sepulveda, A. 2010. "A Novel Demand Side Management Program Using Water Heaters and Particle Swarm Optimization." IEEE, doi: 10.1109/EPEC.2010.5697187.

Torgeir, E. September 2009. "Direct Load Control of Residential Water Heaters." Energy Policy 37(9), 3502–3512, ISSN 0301-4215, http://dx.doi.org/10.1016/j.enpol.2009.03.063.

APPENDIX A

The moving R-squared product equation:

R-squared (all points above breakpoint)*R-squared (all points below breakpoint).

This technique works best in the middle of data sets because as it moves closer to one side of the data, the fit can get very close to one, artificially skewing results. The calculation was performed in Microsoft Excel, using cell formulas. To the authors' best knowledge, this is an original analytic technique developed by Craig Miller and Thomas Kirk.